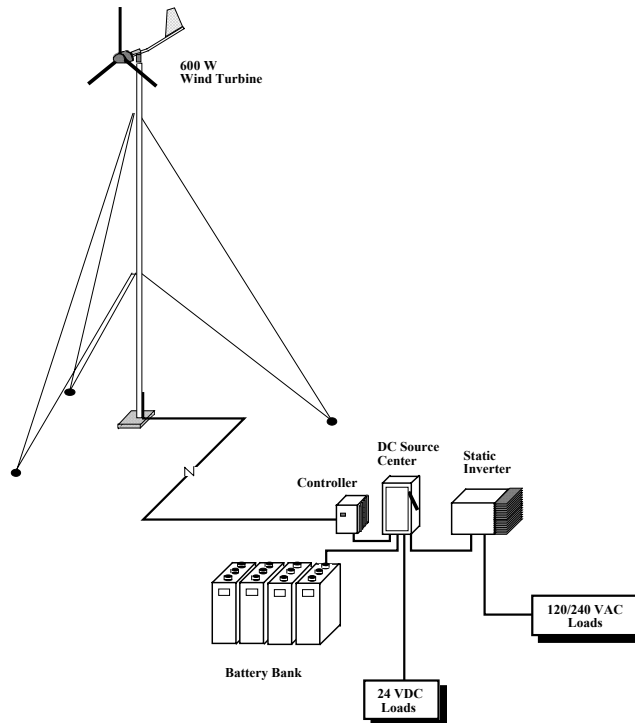




DC-Bus Hybrid Power Systems

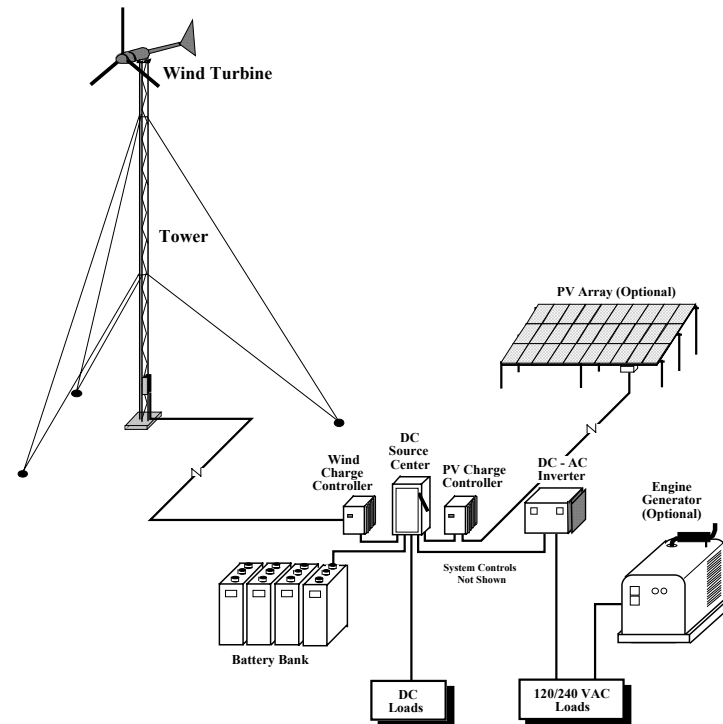
Small Wind Systems Tutorial
Village Power Conference Workshop

Battery and Hybrid Systems



Wind Home Systems

- Micro-Turbines: 60 - 800 Watts
- Both DC and AC Systems
- >150,000 Systems in China



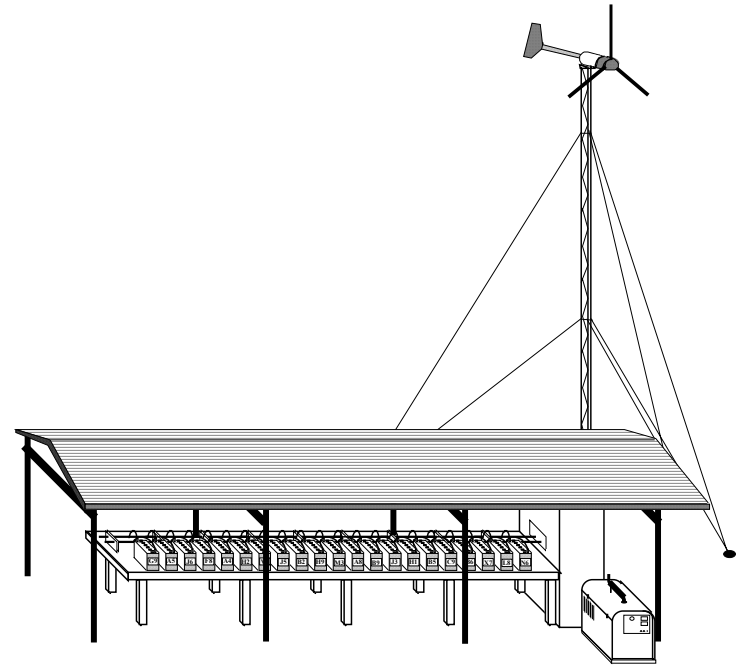
Hybrid Power Systems

- Larger Capacity: 1 - 100 kW
- For Villages and Telecommunications
- 24 HR Power with <10% Diesel Run Time



Battery Charging Stations

- ◆ Carting Batteries to Town for Charging is a Common Practice in Developing Countries
- ◆ Offering Wind/Diesel Powered Battery Charging Services at the Village Appears to be Very Cost Effective
- ◆ Cost Of Service, Including Lights and Battery Delivery Service, Ranges From \$2.50 - \$5.00 Per Month
- ◆ Profitable Public or Private Sector Electrification, Even Serving The Very Poor, Is Possible With This Technology



Diesel Liabilities

- ◆ Systems Operate Inefficiently Due To Low Load Factors
- ◆ Power Is Not Available 24 Hours ... Limits Economic Development (e.g., Daytime Productive Uses) and Some Valuable Applications (e.g., Refrigeration)
- ◆ Manual Controls and Dispatch - High Labor Costs
- ◆ Major Overhauls And Extended Downtime Are Common ... Total Abandonment Of Equipment Not Uncommon
- ◆ Continuing Headache of Fuel Supply
- ◆ Governments Often Have Goal Of Reducing Fuel Use And Expenditures



Hybrid Systems

◆ Wind Turbines and Diesels are Complimentary:

| <u>Characteristic</u> | <u>Wind</u> | <u>Diesel</u> |
|--------------------------|-------------|---------------|
| Capital Cost | High | Low |
| Operating Cost | Low | High |
| Maintenance Requirements | Low | High |
| Available On-Demand | No | Yes |

Together, They Provide a More Reliable and Cost-Effective Power System Than is Possible With Either Wind or Diesel Alone

◆ Wind And Solar Often Have Seasonally Complimentary Resources

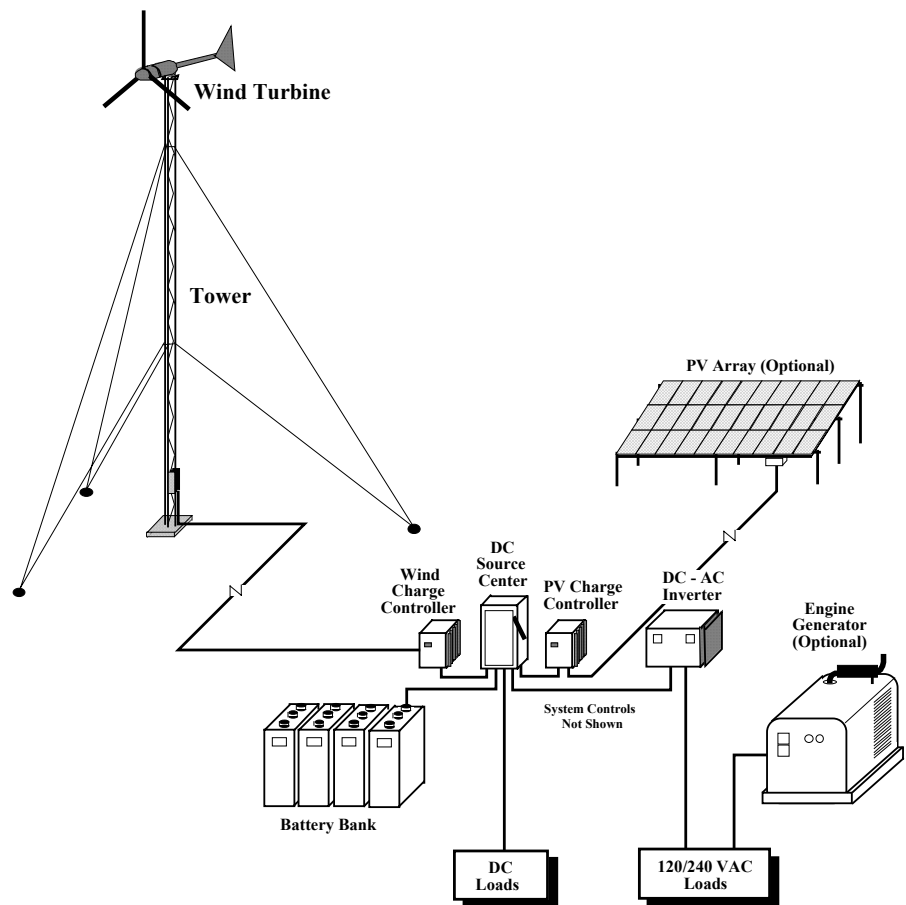
- Summer: Low Wind / High Solar
- Winter: High Wind / Low Solar



Hybrid Systems

The New Way to Electrify Villages

- ◆ One or More Variable Speed Wind Turbines; Optional Solar
- ◆ DC Bus Architecture
- ◆ Lead-Acid Batteries, Flooded Type
- ◆ Sinewave Static Inverters for DC-AC Conversion
- ◆ Back-up Diesel Generator for Low Wind Periods
- ◆ Renewables Typically Supply 60 - 85% of Energy
- ◆ Provides 24 Hr / Day Power with Diesel Run Times Reduced to ~10%



Advantages of Hybrid Power Systems

- ◆ Provide Dependable, Utility-Grade 24 Hour AC or DC Power
- ◆ Not Dependent On Single Source Of Energy
- ◆ Flexible, Expandable, Able To Meet Changing Loads
- ◆ Simple, Quick, Low Cost Installation
- ◆ Low Operating Costs (O&M and Diesel Fuel)
- ◆ Simple Operation, Low Maintenance & Service Requirements
- ◆ User Not Required To Operate, Maintain, or Repair
- ◆ Lower Life-Cycle Cost Of Electricity For Remote Applications



Disadvantages of Hybrid Power Systems

- ◆ High Capital Cost Compared To Diesel Generators
- ◆ Diesel And Hybrids Have Very Different Cost Components
- ◆ More Complex Than Stand-Alone Power Systems ... Requires Battery Storage And Power Conditioning
- ◆ Not Yet In Full Commercial (High Volume) Production ... Few Suppliers

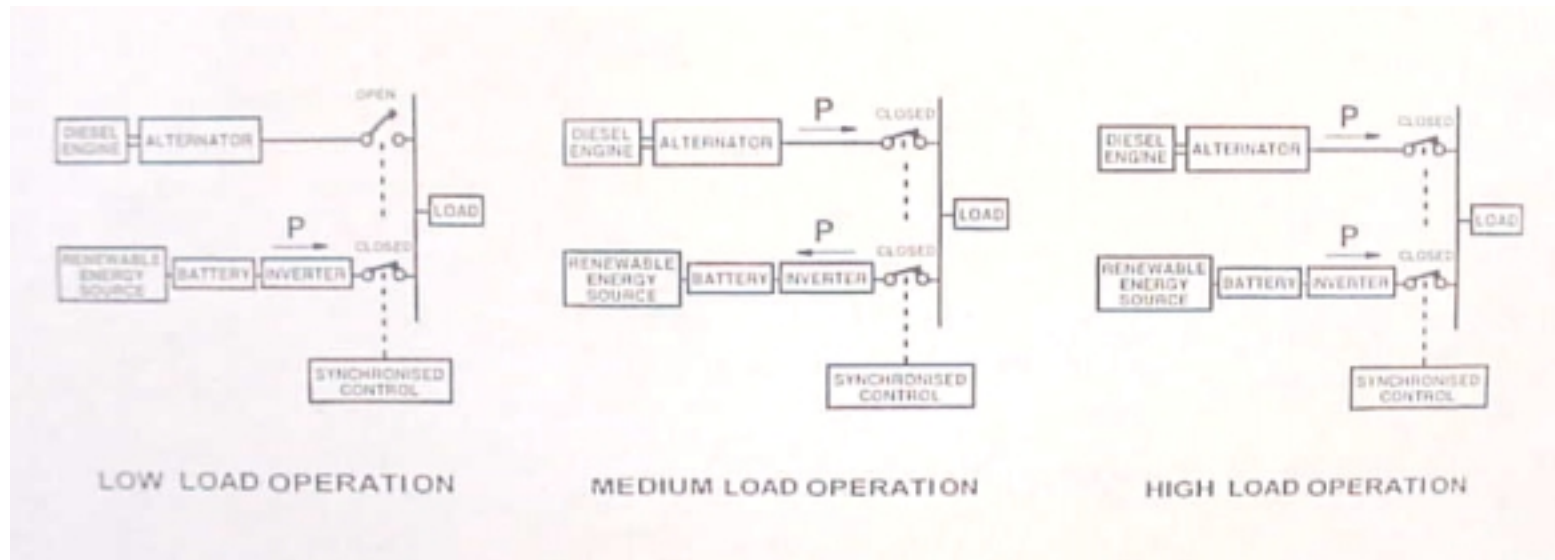


Hybrid System Configurations

- ◆ Very Small Systems (< 2 kWp Total) Usually Do Not Use Back-up Generators And Have Relatively Larger Battery Banks (And Usually Solar Modules)
- ◆ Larger Systems Usually Are Hybrid Systems With A Diesel Generator (And Sometimes Solar Modules)
- ◆ New System Architectures: Rotary Converters And “AC Bus” Systems Are Emerging for Larger Systems

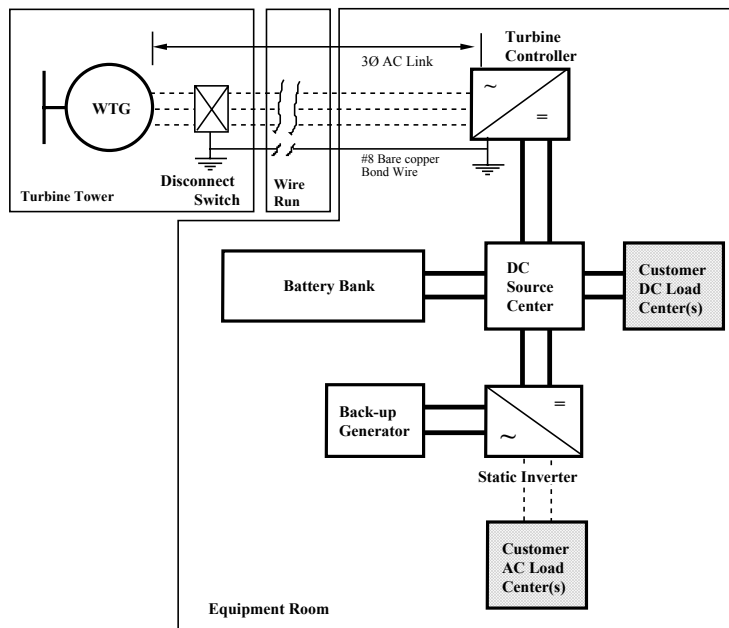


Advanced Inverter Systems

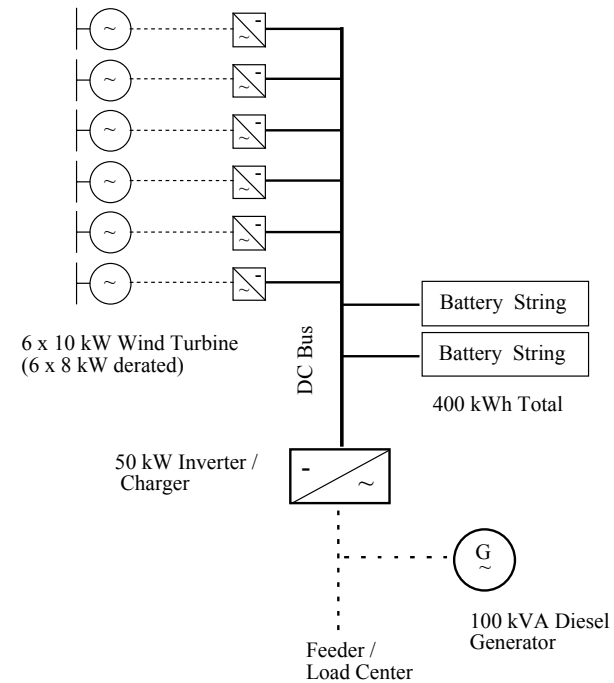


- ◆ Bi-Directional Inverters, Which Include Battery Charging and Load Transfer Capabilities, Allow Back-up Diesels to be Used Efficiently
- ◆ Paralleling Capabilities Can, In Theory, Allow Smaller Inverters and Diesels

DC Bus Architecture



Single Turbine



Multiple Turbines

Static Inverters

- ◆ Inverter Is Often the Critical Component
- ◆ Inverter Technology Has Improved Greatly in Last 5 Years ... Reliability is Now Quite Good
- ◆ Features: Charging, Low Battery Cut Off, Diesel Synchronization (Load Sharing)
- ◆ Small Units Still Mostly Modified Square Wave Output ... Okay, But Can Cause Noise in Light Ballast's and in Communications Equipment
- ◆ Units Above 3 kW Now Mostly Sinewave Output; THD < 5%
- ◆ Efficiencies Run 80-94%; Average is ~90%
- ◆ Costs are Typically \$0.60-1.00/W
- ◆ 50 kW+, 3Ø Units Now Common
- ◆ For Village Power, Leading Suppliers are Trace Engineering (U.S.) and Advanced Energy Systems (Australia)



Batteries I

- ◆ Flooded Lead-Acid Batteries Still the Technology of Choice
- ◆ Deep-Cycle Batteries Required - Vehicle Starting Batteries Last Only 1-2 Years in Deep Cycle Service
- ◆ Sealed Batteries Cost ~50% More ... Too Expensive for Most Village Power Situations
- ◆ Typical Efficiency is ~75%, But Only 40-70% of Generation Goes to Storage - Batteries Only Take Net Power After Load
- ◆ Battery Costs are Typically \$55 - 150/kWh
- ◆ Best Costs on Smaller Systems Achieved in Using High-Volume Golf-Cart Batteries (eg., Trojan T-105: ~\$45/kWh)



Batteries II

- ◆ Batteries Should Not be Discharged Below 80% ... Usable Capacity is ~80% of Total Capacity
- ◆ Batteries Should be Equalized Approximately Monthly
- ◆ Batteries are Connected in Series to Build Voltage and in Parallel to Build Capacity
- ◆ Batteries Can be Paralleled Up to 5 Strings Without Problems
- ◆ Battery Strings Should be Fused or Breakered to Protect for Short Circuits
- ◆ Battery Acid Is a Serious Health Hazard
- ◆ Hydrogen Gas is Generated, Particularly During Equalization
- ◆ The Variable Nature of Battery Charging with Wind Power Seems to Have a Positive Effect of Operating Life



DC Source Centers

- ◆ DC Source Centers Eliminate the Bad Practice of Attaching Sources and Loads Directly to the Battery Terminals
- ◆ Common Connection Point for All DC Sources, Loads, and Storage
- ◆ Incorporates Fuses or Circuit Breakers for Major Components ... Providing Short Circuit Protection
- ◆ Often Constructed Around Multi-pole Switch, Providing Main System Disconnect
- ◆ Usually the Inverter is the Primary Load
- ◆ Costs are \$400 (1 kW) - \$1,800 (20 kW), Costs Primarily Determined by Current Levels
- ◆ Some Suppliers Offer Nice Power Metering Package Options
- ◆ DC Bus Provides Easy Method for Paralleling Multiple Wind Turbines and/or PV Arrays



Controls

- ◆ Typical Hybrid System Control Functions:
 - Battery Overvoltage ... Wind & PV Regulators
 - Battery Undervoltage (Load Shedding) ... Inverter
 - Battery Equalization ... Wind & PV Regulators
 - Back-up Generator Start / Stop ... Inverter or DC Source Center
- ◆ Centralized Controller Which Monitors All Sources and Loads is Not Necessary
- ◆ Most Controls Triggered by DC Bus Voltage (Battery Bank Voltage)
- ◆ State-of-Charge Monitors or Energy Counting (e.g., Net Ampere-Hours) Controls Don't Work as Well
- ◆ Some People Prefer to have Manual Back-up Power, Controlled by Local Operator

